Daylighting and Lighting Technology

Three technologies — daylighting systems, efficient light fixtures, and lighting controls — are powerful tools to reduce electricity consumption in buildings while improving the quality of indoor lighting

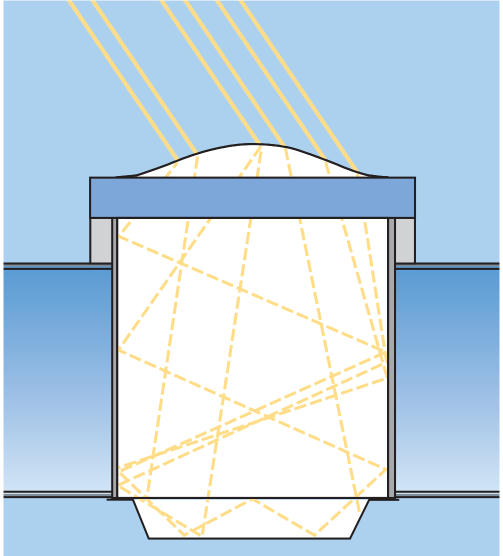

Figure 1. Schematic of a commercial daylighting unit

Daylighting

Daylighting units (as opposed to typical skylights) direct high levels of daylight down reflective wells and diffuse the light properly into the interior of a building to reduce the need for electric lighting. One commercial design (Figure 1) consists of a prismatic dome, a reflective light shaft, and a diffusing lens.

Efficient Light Fixtures

Replacing inefficient light fixtures is a second measure that can reduce energy consumption. Many existing warehouses, hangers, and other Federal buildings employ older-generation lighting fixtures that are less efficient than lighting fixtures now available. For example, a fluorescent T-5 4L HO (i.e., 4-lamp, high-output) fixture draws less than half the power drawn by a typical 400-Watt HID (high-intensity discharge) fixture while providing the same amount of light. Hence, upgrading lighting fixtures alone provides a large energy and cost savings.

Lighting Controls

Lighting controls play a pivotal role in ensuring energy savings. The control system optimizes the interior lighting conditions while minimizing electricity usage. Typical control systems include occupancy sensors that turn off lights when areas are unoccupied and light-level sensors with digital switching technology to turn off groups of lights when the daylighting levels are adequate.

Costs and Performance

Even in locations where electricity costs are relatively low, daylighting projects are cost effective and pay for themselves quickly in energy savings. In the continental United States, the installed cost of daylighting units together with lighting upgrades and controls is, on average, around \$2 per ft^2 of floor area served. Two cost drivers that introduce variability in the cost are the type of roof on which the units are installed and the shipping costs. The expected energy savings also vary with geography: performance is influenced not only by available daylight but also climate (temperatures). In general, however, one can expect to see energy savings in the range of 2.5 to 4.5 kWh per year per ft^2 of area served.

Case Study

In 2004, a daylighting and lighting retrofit project was prepared for 13 large hangers at Nellis Air Force Base, Nevada. Most of the hangers had floor areas of 26,000 ft^2 and were lit by 450-W HID light fixtures. The project envisioned the replacement of these fixtures with T-5 4L HO fixtures and the installation of 20 daylighting units. A lighting control system was specified for each hanger area. The total estimated cost came to \$2/ft^2 of floor area served, and the predicted annual energy savings was 2.75 kWh/year/ft^2 of hanger area served. Given the local cost of electricity of \$0.072/kWh, the project's Simple Payback was 8 years.

Figure 2. Photo of daylighting units in a warehouse shows interior lighting conditions on a partly cloudy day. All electric lights are OFF in this picture!

Potential Cost-effective Applications and Application Criteria

These technologies are generally applicable in large building with ceilings heights of 20 feet or more. Daylighting units plus lighting controls are cost-effective for buildings that are occupied during the daytime at least 5 days per week. If daylighting units are installed in a building, then upgrading the building's light fixtures will generally be cost effective if the facility is operational for at least two shifts.

- Typical buildings include the following:
- Warehouses
- Hangers
- Assembly buildings
- Vehicle maintenance facilities
- Gymnasiums
- Other similar commercial or industrial buildings

Buildings with large open floor areas are particularly efficient for daylighting because fewer units can be utilized to illuminate larger open areas. In warehouses and other buildings that have aisles interspersed with tall storage shelves, attention must be paid to the distribution of the skylights to ensure good lighting in the aisles.

Transpired Solar Collector

A transpired solar collector is a device for pre-heating ventilation air. Its primary component is a dark sheet metal solar absorber mounted to a building's south-facing outside wall. The metal absorber heats outside air, which is then sucked into the building's ventilation system through perforations in the collector. Transpired solar collectors are inexpensive to make and, commercially, have achieved efficiencies of more than 70%.

Transpired solar collector systems exchange the sun's radiant heat to air. The collector's dark-painted metal absorber has holes about 1 mm in diameter and about 3 mm apart. At this small scale, heat transfer is by conduction rather than convection and air flow is by viscosity rather than momentum. The sun heats the plate, which loses heat to the air, but the air is drawn into a small hole before the thin "boundary layer" can mix with the ambient air.

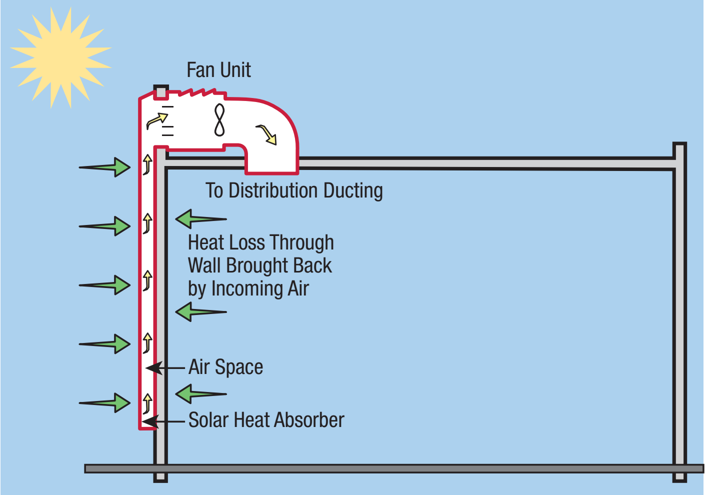

Figure 1. Transpired Solar Collector System Schematic. The transpired collector plate is held about 6 inches away from the south wall by supports to create a plenum. Air is drawn through the wall by a fan. The perimeter is sealed with flashing. It is only for preheating ventilation air — there is no recirculation to the inlet for reheating. A by-pass damper on the face of the wall admits fresh air without heating in summer.

Costs and Performance

When considering a transpired solar collector in retrofit installation applications, system cost is estimated as per the following table

Absorber	\$ 9.50/ft^2
Supports, Flashing, etc.	\$ 2.50/ft^2
Installation	\$ 4.00/ft^2
Other Costs	\$ 4.00/ft^2
Total	**\$20.00/ft^2**

The annual energy and cost savings can be estimated from the solar resource data and the fuel type and cost. Because of the low cost of the simple technology, solar ventilation air preheating competes even with the historically low cost of natural gas. As the cost of natural gas increases, the number of DoD sites that can benefit from the application of solar ventilation air preheating also increases.

Application in warmer climates, such as southern Texas and Florida, are limited because these sites do not need to preheat ventilation air. Many cost-effective applications exist in not-so-sunny locations, such as the northeastern United States because they can use the heat more days of the year. Savings are estimated using a GIS computer program to combine the solar resource on a south wall with the heating requirements of a site.

A typical use is for preheating ventilation air in large spaces. Because of the low cost of this simple technology (about \$20/ft^2 installed) and its high efficiency, more than 2 million ft^2 have been installed, mostly in manufacturing facilities in the Northeast and Canada.


Transpired Solar Collector

Case Study

Transpired solar collector system on AVUM Hangar at Fort Carson, Colorado, is 7,800 ft^2 and saves 1,560 million Btu/year.

Application Criteria

Three key factors indicate whether this solar technology is applicable:

- Heating Degree Days (HDD) - generally >1500
- 100% outside air ventilation for space-heating requirements
- Facility has south-facing (plus or minus 45 degrees) wall (preferably the long wall of a rectangular building)

Examples of facilities that can benefit from air pre-heating include high-bay hangers, Industrial facilities (e.g., paint shops), assembly areas, vehicle maintenance facilities, hospitals, or any other buildings that deliver heated ventilation air to enclosed space.

Solar Swimming Pool Heating

Most Defense facilities have swimming pools for recreation and fitness purposes and the heating of these consumes large amounts of energy. The use of swimming pool covers and solar hot water heating systems are two options that will often save energy in a cost-effective manner. Swimming pool covers frequently pay for themselves in less than 1 or 2 years and should be considered as a matter of course. Solar swimming pool heating systems should also be considered: they are a good application for several reasons:

- the solar collectors in this application operate at a temperature lower than other solar water heating applications so there is less heat loss and the collectors are more efficient
- this low-temperature operation allows for use of low-cost unglazed polymer solar collectors
- the pool itself acts as a huge reservoir of thermal storage, increasing solar utilization
- the solar heating system often utilizes the available pump that filters the water.

Unglazed solar collectors for swimming pools are extruded from a polymer, such as polypropylene with UV stabilizers, and do not have a cover glass or insulation. Flow passages for the pool water are molded directly into the absorber, and pool water is circulated through the collectors by the pool filter circulation pump. They heat water up to 18°F (10°C) above ambient temperature. The temperature rise of the water going through the collectors should be from 3°F to 5°F for the most efficient operation. Thermally insulating these collectors is unnecessary and counterproductive, given that in many days of the year the ambient temperature is warmer than the pool water. However, in cold climates or in wintertime, glazed insulated collectors are required.

Ideally, solar collectors should face south, although an orientation up to 45° east or west of due south will not significantly decrease performance provided that shading is avoided. For optimum pool heating in winter, solar collectors should be tilted at latitude plus 15°.

Cost and Performance

In 2003, 26 manufactures shipped 10,877,000 ft^2 of unglazed swimming pool solar collectors, mainly to Florida, California, New Jersey, Arizona, and Hawaii. The fact that 804,000 ft^2 were sent to New Jersey is an indicator that energy prices and state incentives are as important as the solar resource and commonality of swimming pools. By comparison, only 560,000 ft^2 of glazed, insulated flat-plate solar collectors where shipped in the same year. Unglazed polymer swimming pool solar collectors averaged in price \$2.08/ft^2 that year, as compared to \$16.78/ft^2 for glazed, insulated flat-plate collectors (this price is only for the collector, not for the complete system. RS Means & Co. reports installed system cost of \$17/ft^2 for unglazed swimming pool heating systems).

The size of the solar heating system is determined by minimizing life cycle cost. Often, the optimal size of the solar water-heating system is equal to the surface area of the pool in moderate climates and perhaps half the pool area in very warm climates. A properly installed solar pool-heating system should require very little, or no maintenance. However, regular maintenance of the pool and its filtration system is crucial. Chemicals to maintain pool pH and chlorine levels should be added to the pool water far from the collector intake pipes. The filter should be cleaned as frequently as recommended by the manufacturer to ensure that adequate flow is supplied to the collectors. Systems may be expected to last at least 10-15 years.

Solar Swimming Pool Heating

Case Study

This 2,000-ft^2 unglazed solar system heats a 3,500-ft^2 indoor pool at the Barnes Field House at Fort Huachuca, Arizona. The system installed cost was $35,000 in June 1980. For 25 years, the system has been meeting 49% of pool heating load and saving the Army 835 million Btu/ year of natural gas valued at $5,400/year.

Application Criteria

Unglazed solar swimming pool heaters have broad application and can be found from Miami Florida, to Leadville, Colorado (one of the coldest places in the country). They are suitable for both indoor and outdoor pools. Unglazed collectors can only be expected to heat water 3–4°F (up to 18°F max) above ambient temperature, so they would only be useful in warm seasons or warm climates (glazed collectors would be necessary under colder ambient conditions).

Other factors to consider include the following:

- available space to locate collectors on roof or ground adjacent to pool (50% to 100% of pool area)
- pool is open in swing seasons (spring, fall) when heating is most needed and daytime temperatures are warm
- a large demand for cold incoming make-up water that needs to be heated (high walk-out)
- a good solar resource (annual average more than 4 kWh/m2/day)
- incentives or special financing offered by utilities or government agencies
- high local energy costs (more than $9/million Btu, very common at today's rates, even for natural gas)
- unreliable or difficult-to-deliver fuels for conventional energy supply
- a strong environmental interest by pool owners and other project stakeholders.

Grid-Connected Photovoltaics

Photovoltaic (PV) arrays convert sunlight to electricity without moving parts and without producing fuel wastes, air pollution, or greenhouse gases (GHS).

Arrays can be ground-mounted on all types of buildings and structures. PV direct current output can be conditioned into grid-quality ac electricity, or dc can be used to charge batteries.

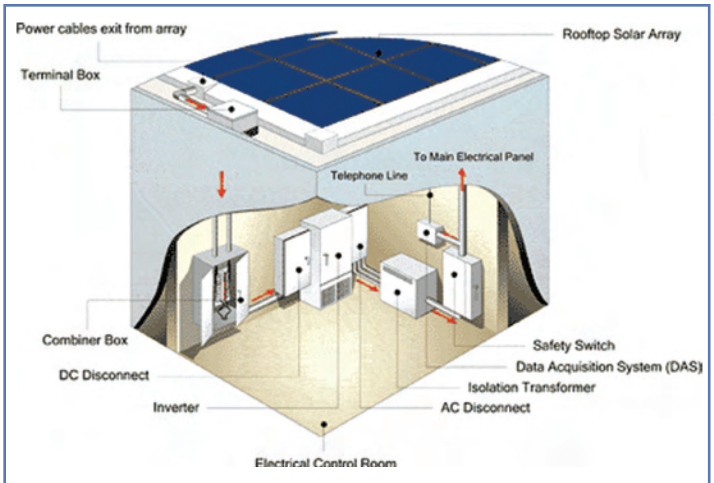

Figure 1. Photovoltaic System Schematic

Cells are either constructed from crystalline silicon cells or from thin films using amorphous silicon. Most systems installed today are in flat-plate configurations where multiple cells are mounted together to form a module. These systems are generally fixed in a single position, but can be mounted on structures that tilt toward the sun on a seasonal basis or on structures that roll east to west over the course of a day.

Costs and performance

The cost of PV-generated electricity has dropped 15- to 20-fold; grid-connected PV systems currently sell for about $5 to $8/Wp. The lifetime levelized cost of the energy they produce ranges from 20 to 32¢/kWh, including support structures and power conditioning (balance of system). Module prices for crystalline silicon, the most common type, are reported at $3.8/Wp and balance of system costs are estimated at $2.7/Wp for a total system cost of $6.5/Wp. Range of total capital cost for all types reported in 2000 is $5.1/Wp to $9.1/Wp, depending on market supply and demand. Operation and maintenance costs are reported at 0.008 $/kWh produced. (John Mortensen, Factors Associated with Photovoltaic System Costs, June 2001, NREL/TP-620-29649, Page 3). Grid-connected PV systems are highly reliable and last 20 years or longer. (Edition 3 of the Power Technologies Energy Data Book, http://www.nrel.gov/analysis/power_databook/toc.html March 2005)

About 288 MW of PV were sold in 2000, and 510 MW of PV were sold in 2002, indicating the rapid growth of this industry. Total installed photovoltaic is now more than 2 GW. The United States world market share is about 20%. Annual market growth for PV has been about 25% as a result of reduced prices, government incentives, and successful global marketing. Specifically, sales grew 36% in 2001 and 31% in 2002. Hundreds of applications are cost-effective for off-grid needs. Almost two-thirds of PV manufactured in the United States is exported. However, the fastest growing segment of the market is grid-connected PV, such as roof-mounted arrays on homes and commercial buildings in the United States. California is subsidizing PV systems because it is considered cost-effective to reduce their dependence on natural gas, especially for peak daytime loads for air-conditioning, which matches PV output.

Current leading PV companies in the United States include Shell Solar; BP Solar; RWE (ASE); AstroPower (now GE); USSC; Global Solar; First Solar; Evergreen Solar; and others. Their combined annual power manufacturing totals 104 MW.

(Edition 3 of the Power Technologies Energy Data Book, http://www.nrel.gov/analysis/power_databook/toc.html March 2005)

Grid-Connected Photovoltaics

Case Study

A 750-kW photovoltaic system also provides shade for 444 cars at Naval Base Coronado in California. The cost is $7.7 million minus $3.6 million in California incentives. The annual cost savings is $228,000.

Application Criteria for Photovoltaics

- Installation/facilities where peak electrical loads occur in summer months
- Installations with electricity tariffs having high ($10/KW +) demand charges for summer months
- Facilities with roof surfaces facing south (plus or minus 45 degrees) or flat roofs (reduces cost of support structures)
- Locations with State financial incentive programs for PV or self-generation (e.g., California provides up to 1MW; Nevada provides up to 30 KW).